Ventilation of Potatoes in Storage Boxes

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ABSTRACT

Sufficient ventilation of table potatoes during storage is important to maintain the tuber quality. A preceding study has already reported on a potato harvester in which the potatoes were filled gently into storage boxes with the aid of a filling device on the harvesting machine (Maly et al. 2005). As subsequent investigations have shown, the foreign material was distributed uniformly between the potatoes with this filling method (Hoffmann et al. 2007).

In order to find out what influence the foreign material has on ventilation of the boxes, the pressure loss of the air in the potato pile was determined in a laboratory experimental rig. The foreign material was distributed uniformly in the pile. In a second stage the air flow profile was studied as a function of the foreign material distribution.

Following the laboratory experiments the climate in a box store that had been filled on the harvester was examined. The entire box store is ventilated by free convection. During a storage period the parameters measured included the air and tuber temperatures, as well as the air velocity during flow through the box. A suitable method was developed to determine the air velocity through the pile in the box.

With only 5 % foreign material, the pressure loss in the potato pile doubled by comparison with the pile free of foreign material, provided that the foreign material was distributed uniformly in the pile. The box middle was not ventilated at all if foreign material was concentrated in this area.

A temperature difference of 1 °C between the tubers and the store air with free convection in the box store led to an air rate of 34.6 m^3/t•h. During the main storage phase the average temperature difference was only 0.26 °C; this corresponds to an air flow rate through the potato pile of 13.2 m^3/t•h.

Only slight weight losses were ascertained in the tubers during the storage period with free convection ventilation.

Keywords: Potatoes, harvest, storage boxes, foreign material, air flow

1. INTRODUCTION

In North America many farmers prefer loose storage of potatoes (Bushman 2005). In Germany table potatoes are also stored loose in boxes or bulk stores, but 41 % of store keepers use boxes to store table potatoes (Hohenlöchter et al. 2005). Box stores provide a whole range of advantages (Pötke 2004, Hohenlöchter et al. 2005):

- the potatoes can be taken into and out of storage quickly
- the tubers are subject to only slight mechanical stress as the boxes are filled and emptied just once
- the boxes are practical and easy to use
- the batches are separated exactly, flexible grading
- individual containers are accessible at all times
- existing buildings can be used
- the potatoes are well ventilated.

In order to be able to harvest, transport and store potatoes as gently as possible, a device was developed for filling storage boxes on the harvesting machine (Maly et al. 2005). This process was termed "direct box filling". When the boxes are filled on the harvesting machine, the tubers and foreign material are filled in the boxes in layers (Hoffmann et al. 2007). The foreign material is thus distributed uniformly between the tubers.

On ventilation of boxes a distinction is made between forced ventilation, impeller fan ventilation and ventilation by free convection. In forced ventilation with fans it is possible to produce defined ventilating conditions selectively. In impeller fan ventilation fans are also used in order to circulate air in the storeroom. In free convection the air flow in the store results solely from temperature differences in the atmosphere. No fans are used. This procedure is interesting for many farmers because it does not involve any costs for drive energy, or for fans and air ducts.

However, in free convection it is in principle uncertain with what intensity individual boxes or parts of boxes will be ventilated. The foreign material certainly has a major influence on box ventilation.

The objective of this study was to ascertain how the proportion and distribution of foreign material in the storage boxes affect potato ventilation and whether uniform distribution of the foreign material during direct filling allows good ventilation of boxes with free convection (Maly et al. 2005). In preliminary tests the aim was to clarify how the proportion and distribution of foreign material affect the air flow.

Direct filling was compared with indirect filling, where the boxes stand on the transport vehicle and are filled from the hopper of the harvesting machine.

2. KNOWLEDGE STATUS

Several investigations were published about the heat, mass and momentum transfer caused by forced air ventilation in agricultural or artificial bulk material (Rettig et al. 1972, Huzayyin et al. 1973, Gottschalk and Christenburg 1998, Tassou and Xiang 1998, Xu and Burfoot 1999a 1999b, Xu et al. 2002, Nahor et al. 2005, Gottschalk 1999). The air flow by forced ventilation is determined essentially by the ventilation system.

By contrast, an air flow caused by self-heating or natural ventilation is largely undefined. It is assumed that an air flow only occurs in the potato pile when the air lift pressure as a result of the temperature difference between tubers and ambient air becomes high enough to overcome the flow resistance of the potato pile (Maltry 1996, Gottschalk 1999). Different values were published to the amount of the air flow rate (Table 1).

Table 1. Air flow in a potato pile by free convection, self heating and room ventilation

Author	Remarks	Information about the air flow
Room ventilation		
Gottschalk 1999	potatoes, over head ventilation ΔT=1 to 2 K	0.002 – 0.03 m/s, calculated
Retting et al. 1972	potatoes H=1 m; ΔT=1 and 20 K	α=120...800 h^{-1} and 1650 h^{-1}, measured
Gottschalk and Christenburg 1998	peaches	0.05-0.1 m/s
Nahor et al. 2005	pears, cool room	air velocity profile, calculated and measured
Self heating (natural convention)		
Hylmö 1976	potatoes, H=4 m; ΔT=7 K	2.3 m3/ t•h, no data
Burton et al. 1955	potatoes H= 6 – 12 ft.; ΔT=3 K	7.8-11.4 m^3/ t•h,
Beukema at al. 1982	potatoes, apples	0.013 m/s, calculated
Free convection ventilation		
Maltry 1996	potatoes, H=1 m; ΔT=1 K	26 m^3/t•h, calculated
Kern et al. 2002	potatoes	10...20 m^3/ t•h, calculated
Hauschild et al. 2004	potatoes	11 m^3/ t•h, calculated
Schierhorn 1997	potatoes, H=4.8 m; ΔT=0.1 and 0.5 K	1.8 and 9.2 m^3/ t•h, calculated
Leppack 1997	potatoes, free convection ventilation, ΔT=1 K	9 to 25 m^3/ t•h, calculated

ΔT temperature difference between the colder room air and the warmer potatoes
H pile height

Some publications reported about the cooling or heating of agricultural products by natural convention in impermeable containers (Sing et al. 1993, Casada and Young 1994, Beukema et al. 1982) and permeable gunny bags (Chourasia and Goswami 2006a, b) or large bulk stores (Hylmö et al. 1975, Hylmö et al. 1976). In all these cases the heating or cooling of a potato bulk by itself was considered. Only few publications are available with information regarding the air flow. Burton et al. (1955) calculated on close boarded and slatted boxes (6-12 ft. height) an air velocity flow of about 7.8-11.4 m^3/t•h for free convection by approximately 3 K temperature difference between potatoes and storage air. Hylmö et al.

(1976) specifies an air flow rate of 3-5 m³/t•h at a potato bulk height of 4 m. An air velocity of 0.013 m/s by natural convection in a ventilation test stand was calculated by Beukema et al. (1982).

However, few literature is available about natural or free air convection in potato bins as ventilation process. This ventilation process requires an air supply to the bins from below.
The calculation of the minimum existing air flow rate from the weight loss is based on the water loss of the potatoes due to transpiration. The quantity of water vapour given off from the box during the storage period via air change is the measure for the minimum airflow (Leppack 1997, Pötke et al. 1999, Schierhorn 1997, Kern et al. 2002, Hauschild et al. 2004).
Maltry (1996) developed an air flow model for the ventilation of potato bins by free convection based on the buoyancy force. He calculated an air flow rate of 26 m³/t•h at 1 K temperature difference for a potato bin height of 1 m. The bottom and the side walls of the bins were made of thin strips of timber.

Only a few scientists tried to measure the air flow resistance or the air velocity in bins (Matthies 1956, Dau 1991, Gottschalk and Christenbury 1998) or storehouses (Nahor et al. 2005). Matthies (1956) ventilated different agricultural products in an experimental arrangement und developed an equation for the determination of the resistance of agricultural products to air flow through the bulk.
In studies by Rettig et al. (1972) radioactive noble gas KR-85 was used to measure the number of air change cycles in bins as a function of various box designs and ventilation conditions. Retting (1972) investigated only forced air ventilation.
Dau (1991) measured the air velocity caused by forced air ventilation in defined sphere beds and found out, that the measured pore velocities were 3 to 4 times higher than the theoretical pore velocities.

In free convection ventilation it is generally difficult to measure the air flow in the box because the air rates frequently lie below the measuring range of conventional measuring technology (Kocsis et al. 2004).

Another problem results from foreign material in potato bins, because the foreign material has a major influence on the airflow rate through the potato pile. Depending on the proportion of foreign material, the flow resistance of the potato pile can rise by up to 500 % by comparison with potato piles free of foreign material (Matthies 1956). Neale and Messer (1976) found out that the soil and trash content had more affect on the resistance of a air flow sample than the variations in the physical properties of the crop itself. Horlacher (2004) presumed that even relatively small foreign material content that are concentrated in a box area can make sufficient ventilation of the potato pile more difficult.

The airflow rates determined by measuring methods and mathematical models were stated for different temperature differences, pile heights and tuber sizes and therefore do not provide any uniform picture (Table 1).

Previous laboratory experiments on ventilation of potato piles have only been conducted for uniform foreign material distribution within the box (Matthies 1956). Irregular distributions of foreign material such as occur in practice were not considered.

The airflows in boxes in free convection under real climate conditions in box stores are completely unknown.

3. MATERIAL AND METHODS

3.1 Experimental Plan and Sequence of Experiments

The measurements on air velocity were conducted during the storage period 2004/2005 at the firm Friweika Weidensdorf e.G. (Germany, Saxony) and formed part of a 3-year trial of a harvesting machine with a box filling device (Maly et al. 2005). The firm Friweika Weidensdorf maintains a store for 4t-boxes with a storage capacity of 15,000 t potatoes. The box store is divided into sections. The boxes are stored in the sections in 7 levels above one another and in 7 rows behind one another. The store is ventilated exclusively by free convection. Ventilation dampers for ventilation are arranged at the bottom on the hall walls and in the middle at the top in the roof ridge. Next to the box store there is also a store in which roughly 15,000 t potatoes are stored loose in bulk.

In the first part of the study the flow resistance of the potato pile was first determined under laboratory conditions with different foreign material contents. After this it was examined how the distribution of the foreign material affects the flow profile and temperature distribution in the potato pile. The foreign material consisted of loose soil and small lumps of soil with a diameter of < 2 cm. Potatoes of the variety Nicola in the size fraction 35 – 45 mm were used for all measurements.

In the second part the airflow was measured in a potato box with free convection ventilation under practical conditions at the Friweika box store.

3.2 Flow Resistance as a Function of the Foreign Material Content

In order to find out how the foreign material increases the flow resistance a cylindrical container (Figure 1) with a diameter of 500 mm was filled with 150 kg potatoes in the experimental laboratory. This corresponded to a filling height of 1 m. No foreign material, or foreign material of 5, 10, 15 or 20 % by weight was added to the potatoes. The foreign material was distributed uniformly between the potatoes.

For each content of foreign material the flow resistance was measured as a pressure difference to the atmospheric air pressure at 4 pile heights (Figure 2). The measurements were conducted with an Airflow 5 measuring device from Messrs. Airflow. The speed of the ventilation air delivered by a blower was increased in 6 stages from 0.08 m/s to 0.48 m/s. The velocity data relate to the free container cross section.

In the potato pile without foreign material the measurements were compared with values calculated in accordance with the empirical equation (1) by Matthies (1956):

$$\Delta p = 0.232 \cdot k \cdot \frac{h}{\varepsilon^4} \cdot \frac{{v_Q}^{1.81}}{{d_K}^{1.19}} \qquad (1)$$

Δp Pressure loss [Pa]
k Material constant, for potatoes k = 1,4
ε Pore volume, for potatoes without foreign material ε = 0,4
h Pile height [m]
v_Q Air velocity related to the bulk material-free cross section of the container [m/s]
d_K Diameter of a sphere of the volume of an average potato [m]

Figure 1. Ventilation test rig with cylindrical container

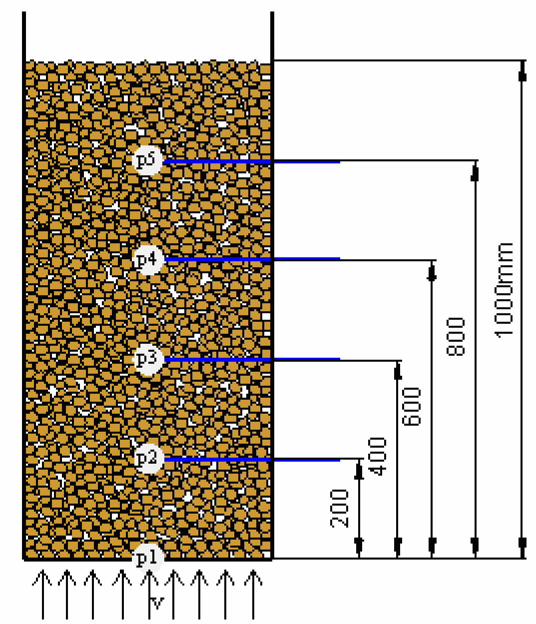


Figure 2. Schematic representation of the pressure measuring points

3.3 Flow Profile as a Function of the Foreign Material Distribution

In a further experiment it was interesting to ascertain how the spatial distribution of the foreign material in the box influences the flow profile. A square container with a length of 1300 mm, a width of 1175 mm and a height of 600 mm and closed sidewalls was used for the experiment (Figure 3). The dimensions were selected in the ratio 1 : 2 in relation to the 4t boxes used at Friweika. The container was filled with 500 kg potatoes.

In order to be able to translate the investigation results into practice, the examinations concentrated on three variants of foreign material distribution:

- Variant 1: The tubers were filled in the box without foreign material. This variant represented the box yard filling at which the foreign material can be separated.
- Variant 2: 25 kg loose soil was added to the tubers when filling the container, whereby the soil is spread uniformly over the cross section. This equal distribution results during "direct box filling" in which tubers and foreign material are filled into the boxes in layers by the filling device on the harvesting machine so that there is no demixing (Hoffmann et al. 2007). The soil quantity corresponded to a foreign material content of 5 % by weight.
- Variant 3: The tubers were filled into the boxes together with 25 kg loose soil. The loose soil was filled into the upper part of the box in the middle of the box (Figure 4). This foreign material distribution was found in preceding examinations in "indirect box filling" (Hoffmann et al. 2007). The concentration of the foreign material in the box middle results from demixing of tubers and foreign material when filling the hopper and in subsequent handing over of the tubers in boxes standing on the transport vehicle.

Figure 3: Ventilation test rig with square container, infrared thermographic camera in the rack tip

In order to determine the dependence of the flow profile on the pile height a tuber layer of only 200 mm (Level A) was first filled in the container (Figure 4). Then the surface of the potato pile was divided into 36 subsections with a surface area of 200 x 180 mm. The airflow through each section was measured with the aid of a measuring hopper with built-in thermo anemometer (Lambrecht 642 ST, measuring range 0 to 2 m/s, resolution 0,01 m/s) (Figure 5). The air flowing into the rectangular part of the measuring hopper from below was brought together on its way upwards into a cross section smaller by a factor of 10. Consequently the air velocity of the cross section increased and could thus be measured with the thermo anemometer.

In order to be able to convert the air velocity v_C measured in the circular reduced cross section of the measuring hopper to the air velocity v_R in the bulk material-free cross section of the container, the measuring hopper was calibrated in a experimental air duct (Figure 6). The air velocities v_R and v_C where measured three times over vertical axis of symmetry on the rectangle (v_R) respectively circular (v_C) cross section. For a regression analysis the mean value of three measured values were used.

This resulted in a conversion formula (2) for the measuring range 0.1 m/s $\leq v_C \leq$ 2.2 m/s:

$$v_R = 0.028 \cdot v_C^2 + 0.1022 \cdot v_C + 0.0039 \qquad R^2=0.98 \qquad (2)$$

v_R Air velocity in the rectangle cross section related to the bulk material-free cross section of the container [m/s]

v_C Air velocity measured in the constricted circular cross section of the measuring hopper [m/s]

R^2 Coefficient of determination

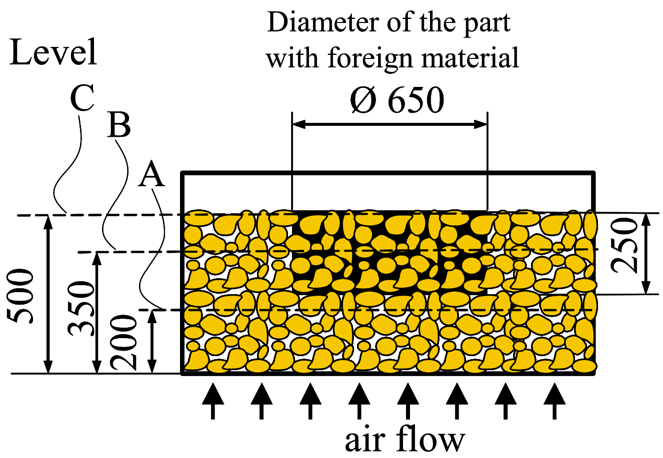


Figure 4. Division of the container into 3 levels, filling variant indirect (Variant 3)

Figure 5. Hopper for measuring low air velocities

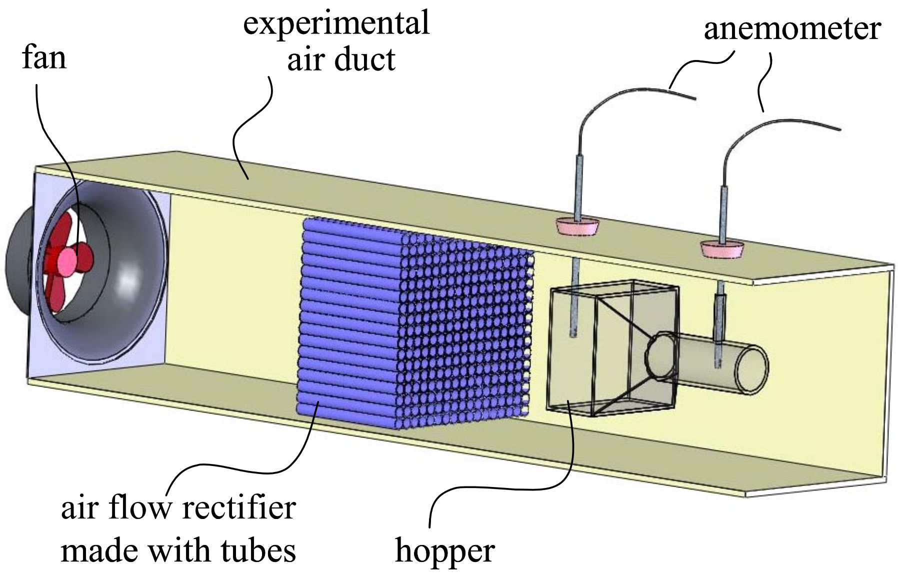


Figure 6: Experimental design for the calibration of the hopper (The air duct front side is faded)

The calibration measurements resulted to a calibration equation with a small confidence limit of the regression line (Figure 7). In the case of $v_C = 0.1$ m/s the mean value of v_R is defined by the 95% - confidence interval $0 < v_R \leq 0.032$ m/s.

The measurement at the 36 subsections was conducted for the air velocities from 0.04 – 0.21 m/s related to the free container cross section. After the flow velocities in the subsection of Level A were measured, the measuring sequence was repeated after filling up Level B and Level C.

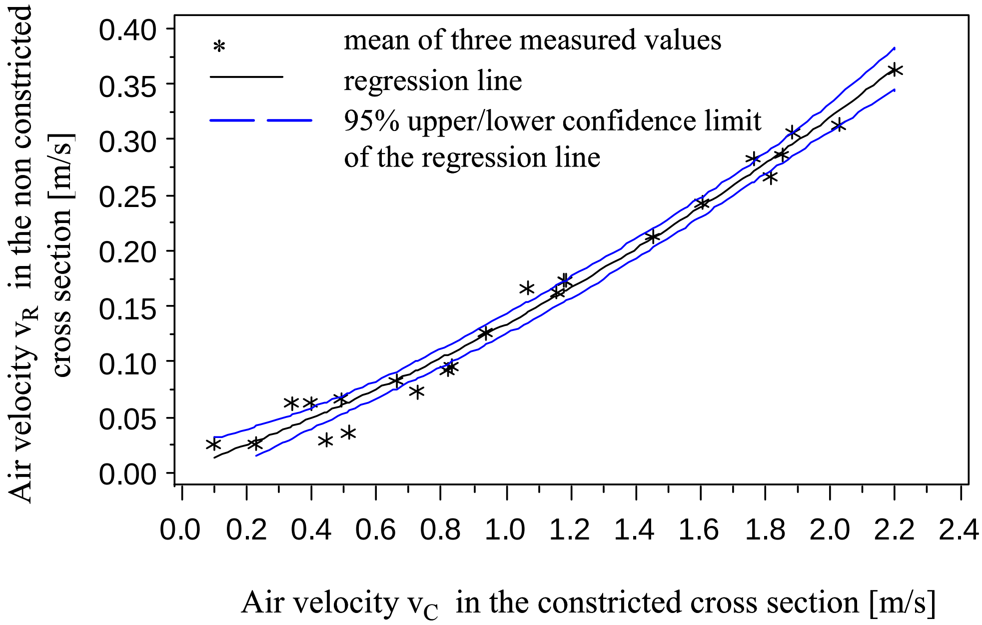


Figure 7: Regression line for the calculation of the measurement hopper

In order to make the effect of the air distribution visible, the experimental container was filled with 500 kg tubers and with tubers and foreign material, and ventilated for 8.3 h from an initial temperature of 20°C with air at a temperature of 14.2 °C. The ventilation was conducted with atmospheric night air. During ventilation the temperature distribution on the box surface was recorded with an infrared thermography camera (Figure 3).

3.3 Ventilation of Potato Boxes in the Store with Free Convection Ventilation

In order to create comparable conditions for ventilating the boxes in the store, the tubers were harvested from the same field at the same time with the processes "direct filling" and "indirect filling" and stored in one section of the box store.

The measurements were conducted with the variety Princess. Prior to the start of measurements four boxes were selected at random and examined for their content of foreign material and size fraction (Table 2). The content of foreign material at 4.12 % by weight was close to the foreign material content of 5 % by weight used for the flow profile in the laboratory tests. The boxes for determining the foreign material were excluded from further examinations.

Table 2. Content of harvested material in the boxes for the variety Princess

	Potato size fraction [mm]					foreign material
	> 80	60-80	50-60	35-50	< 30	
Content of harvested material*) [% by weight]	0.15	31.48	35.13	28.42	0.70	4.12

*) Mean values of 4 boxes

In order to be able to obtain information on the airflow through the potato pile during free convection ventilation, selected parameters on climate within the boxes (box climate), within the storeroom (storeroom climate), and outside the storeroom (outdoor climate) were measured (Table 3).

Table 3. Distribution and number of measuring sensors

		Measuring principle	Number of measuring sensors Box climate direct	indirect	Storeroom climate	Outdoor climate
Tuber temperature	°C	Pt 100 insertion thermometer	20	20	-	-
Air temperature	°C	NTC – sensors	3	3	6	4
Air humidity	%	Capacitive sensors	3	3	4	4
CO_2 content	%	IR optical CO_2 sensor	3	-	2	1
Air flow	m/s	Thermo-anemometer	1			
		Impeller			1	

It was primarily interesting to see how the boxes that had been filled directly are ventilated. That is why sensors for air temperature, air humidity and CO_2 content were placed in three boxes already during filling on the field (Figure 8).

In one box the measuring hopper already used for the laboratory experiments was inserted to measure the air velocity approx. 20 cm below the surface of the potato pile (Figure 9). The box with the measuring hopper was stored in the bottom stack level in the middle row of the store section.

Figure 8. CO_2 gas sensor, temperature and moisture sensors in the middle of the box

Figure 9. Measuring hopper with anemometer for measuring the air velocity

Insertion thermometers were placed in a further 20 boxes to measure the tuber temperature. By analogy 20 boxes that had been filled indirectly were equipped with insertion thermometers. These temperature measuring points were to be used to determine how large the temperature differences are between boxes that have been filled directly and indirectly.

All climate measurements in the store and in the boxes were conducted with data loggers and sensors from Messrs. AHLBORN. The measuring period ranged from storage intake on 10.09.2004 to storage outtake on 12.03.2005. The measuring interval was 1 hour.

For the variety Princess the weight losses in direct and indirect filling were determined with the aid of balance bags as a measure for the tuber quality. In addition to the variety Princess, balance bags were placed in the boxes for the variety Sanira too, and in the preceding two years of investigation such bags had been inserted in the boxes of six further batches. The balance bags always contained approx. 5 kg clean, externally undamaged tubers. Alongside data for box storage, weight losses for bulk storage were also determined.

4. RESULTS AND DISCUSSION

4.1 Flow Resistance as a Function of the Foreign Material Content

The measurements on pressure loss in potato piles without foreign material confirmed the linear connection known from equation (1) between pile height and pressure loss.
For potato piles with foreign material it was also possible to ascertain a linear connection between pressure loss and pile height provided that the foreign material was uniformly distributed among the potatoes. On the basis of this linear connection it is expedient to state the pressure loss related to 1 m pile height.
Independently of the air velocity selected, the pressure loss increased at 5 % foreign material to double the amount, at 10 % foreign material to 5-fold the amount, and at 20 % to 15-fold the amount by comparison with the piles without foreign material (Figure 10).
Matthies (1956) reported an increase in flow resistance of 10 % to 500 % depending on the quantity and condition of the foreign material. The upper value of 500 % was reached in our own measurements already at 10 % foreign material.

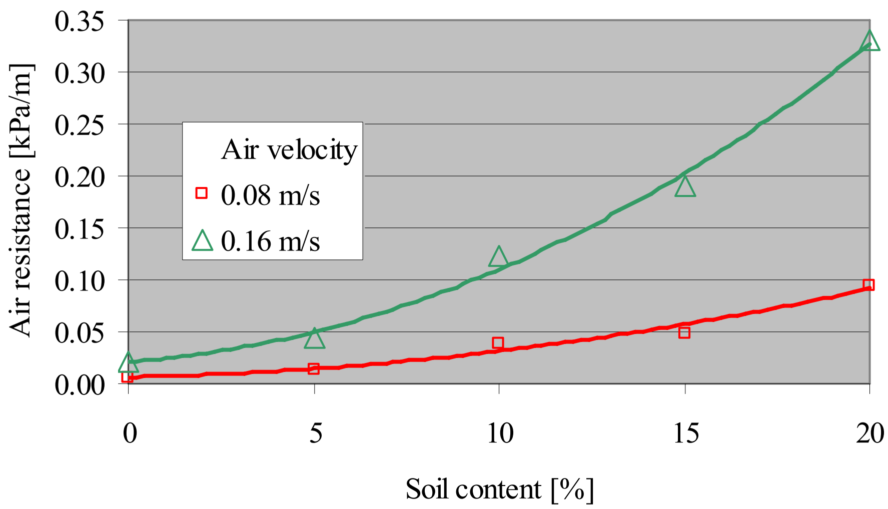


Figure 10. Flow resistance as a function of the foreign material content and the air velocity related to the free container cross section

4.2 Flow Profile as a Function of the Foreign Material Distribution

If potatoes and foreign material were distributed uniformly in the box as with direct box filling (Hoffmann et al. 2006), a relatively uniform flow profile was found over the box cross section for the lower and middle levels A and B (Figure 11). The air flowed through the entire box cross section including the middle of the box. Air also flowed through the middle of the box in the upper level C, but the edge/corner influence dominated in the flow profile. At the edge of the box and in the box corners the airflow reached maximum values due to the large pore volume between the box wall and the adjacent tubers.

A comparison of the three filling variants (Figure 12) showed that in the case of direct box filling air flowed through the middle of the box in a similarly good manner as for variant 1 free from foreign material. In the case of variant 3 hardly any or no air flowed through the middle of the box with the foreign material.

Since the flow profiles are in principle symmetrical profiles, it is sufficient for the profile presentation to simply display a simplified profile over the middle width of the box. On the basis of the even number of sections on each side of the container it is not the geometrical middle of the box that is measured, but instead an area offset by one width of the measuring hopper. That is why for the sake of simplification the measurement row 3/6 box width should be assumed as middle of the box.

The simplified profiles of the filling variants confirm the inlet air at different velocities too (Figure 13), showing that the uniform distribution of the foreign material ensures good ventilation by analogy with the pile free of foreign material. By comparison, if the foreign material is concentrated in the middle of the box, a customary foreign material content of 5 % is already sufficient to block airflow completely.

In agreement with the flow profiles the measurements with the thermography camera also showed uniform temperature distribution for the variant box yard filling (without foreign material content) (Figure 14a). For the variant of direct filling deviations from the uniform cooling of approx. 1° C were measured (Figure 14b). The maximum temperature differences were measured at the surface of the potato pile in the variant indirect filling. The maximum temperature difference between the middle and the edge after 8.3 hours was 4° C (Figure 14c). The tubers and foreign material formed an approximate closed body. The heat volume contained in the tubers and foreign material first has to be transported to the box surface by heat conductivity before it can be given off to the air.

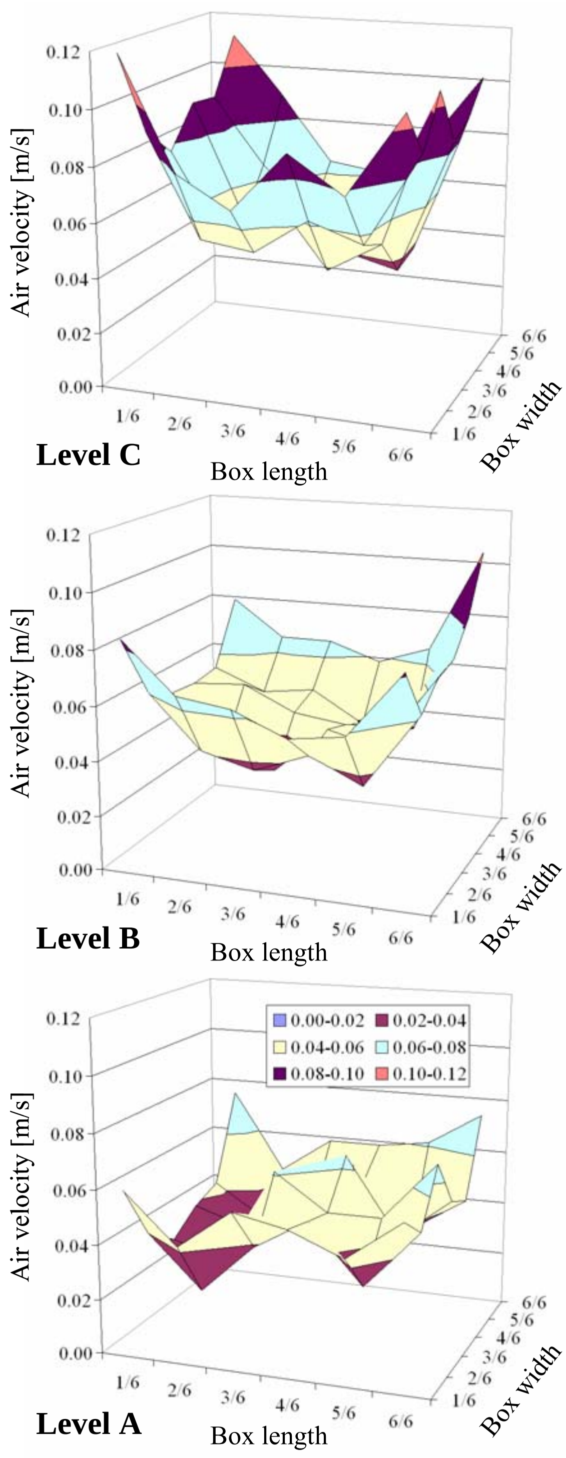


Figure 11. Air velocity spread in a potato box with even spread of foreign material, Variant 2, 0.08 m/s air velocity in the free container cross section

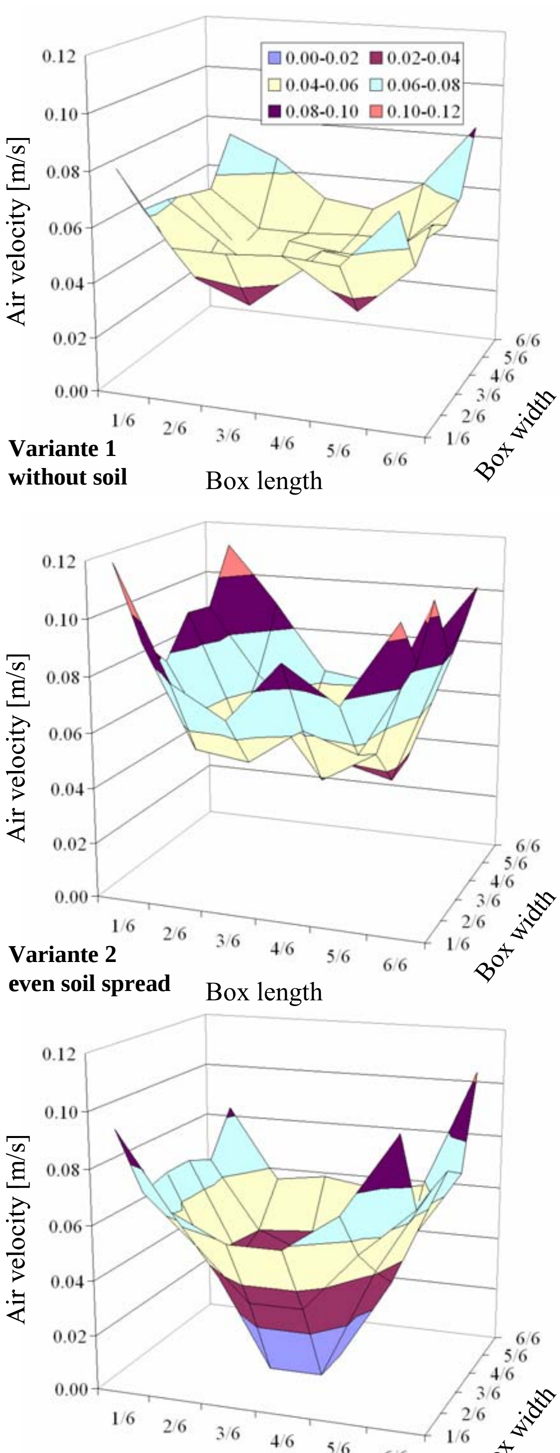


Figure 12. Flow profile at level C at an air velocity of 0.08 m/s in the free container cross section

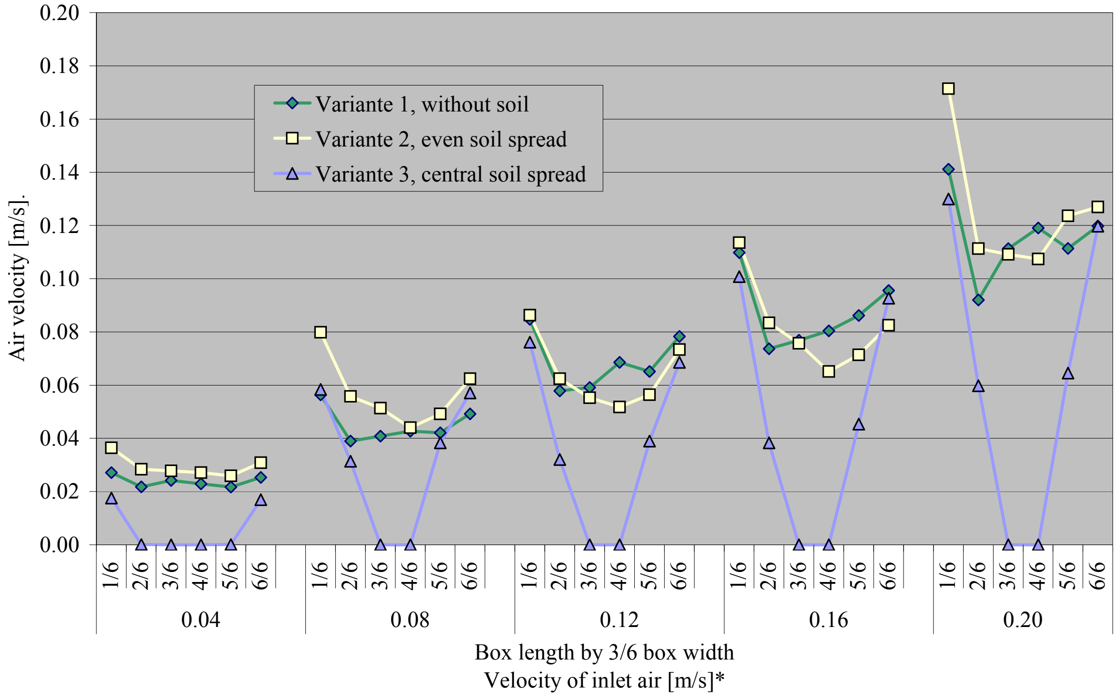
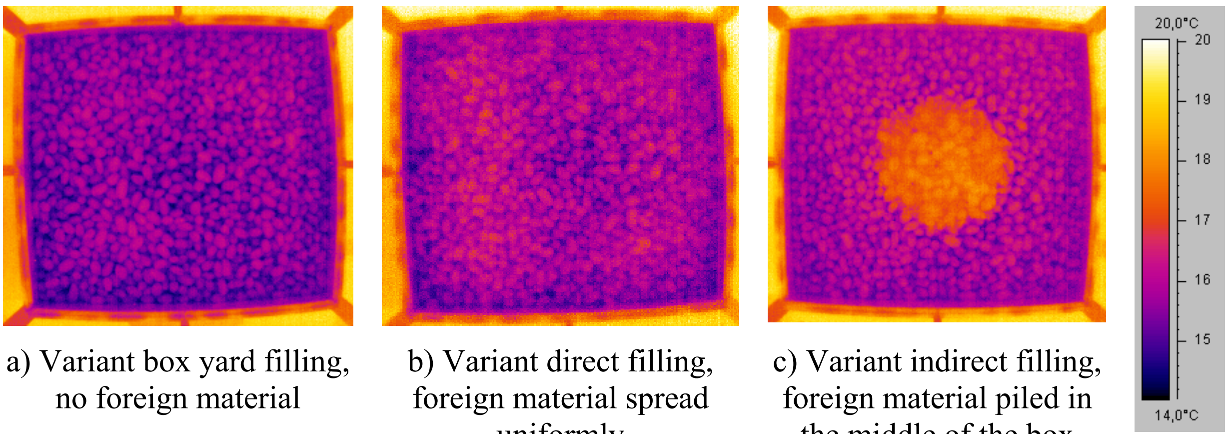


Figure 13. Simplified flow profile as a function of the filling variant and inlet air velocity
* Air velocity related to the free cross section



a) Variant box yard filling, no foreign material

b) Variant direct filling, foreign material spread uniformly

c) Variant indirect filling, foreign material piled in the middle of the box

Figure 14. Temperature distribution on the surface of the potato pile after 8.3 h, cooling, measured with an infrared thermography camera

4.3 Ventilation in the Real Box Store

The measurements of the box and storeroom climate during the main storage phase reveal that the air exchange in the directly filled box depends on the temperature difference between the tubers and storeroom air (Figure 15). If cold outdoor air entered the storeroom when the ventilation dampers were opened (Figure 15, point A), the storeroom temperature cooled down. When the storeroom temperature was cooled below the tuber temperature (point B), air lift developed within the potato pile. The air lift led to air flowing through the box, measured on the basis of the air velocity in the measuring hopper. The air velocity increased as the temperature difference between the tubers and the storeroom air increased. Heat, moisture and CO_2 were passed out of the boxes by the air exchange. After the ventilation dampers were closed (point C), the storeroom air temperature increased again.

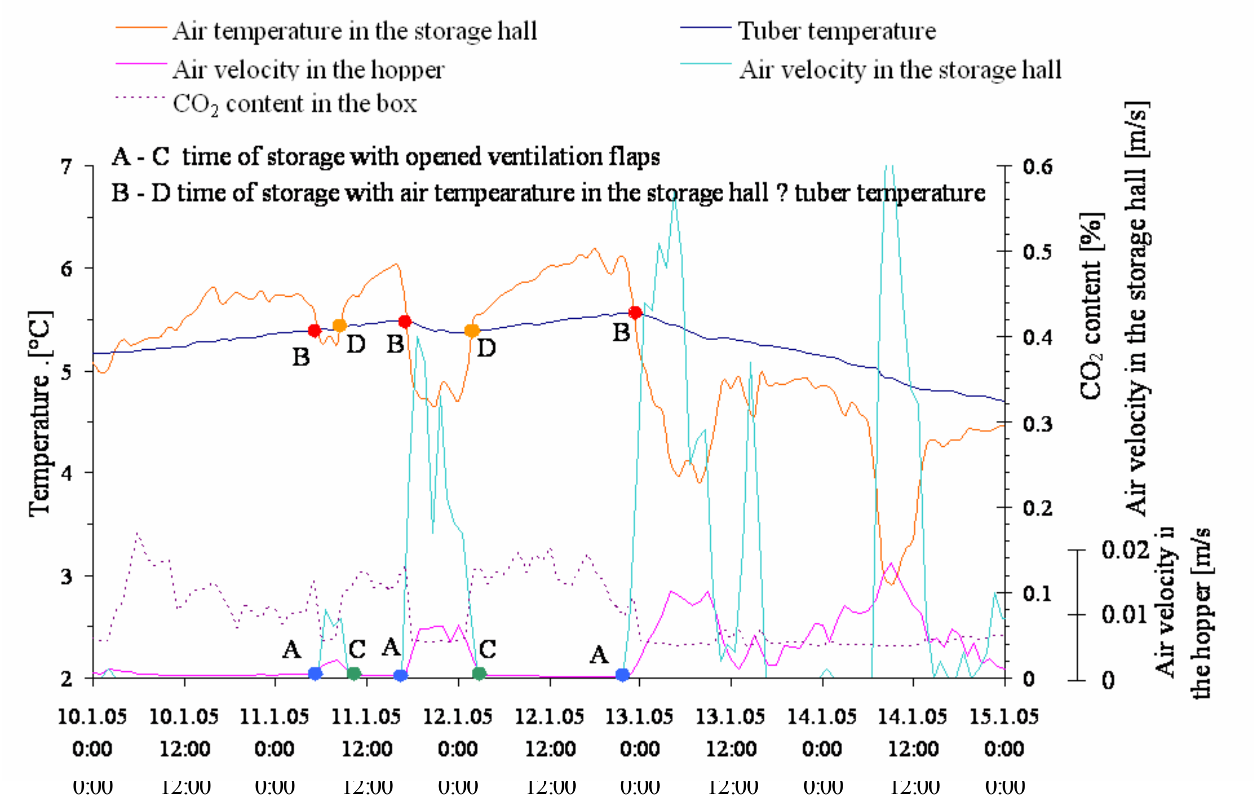


Figure 15. Connection between storeroom and box climate within
2 days during the main storage phase

The air lift in the box was retained until the storeroom air temperature had risen above the tuber temperature (point D). The tuber temperature, the moisture and the CO_2 content in the box also increased further until the storeroom air temperature again dropped below the tuber temperature.

The air velocity in the measuring hopper related to the free cross section rarely reached values over 0.01 m/s. This air velocity corresponds to an air rate of 55 $m^3/t{\bullet}h$.

After cooling down the potatoes were stored for altogether 3144 h in the storage period 2004-2005. During 67 % of this time the storeroom air was colder than the tubers. This resulted in an average temperature difference between the tubers and the storeroom air of 0.26° C.

During storage the air velocity in the measuring hopper and the temperature difference between the tubers and storeroom air were stored as pairs of values. On the basis of these measurements a linear connection becomes apparent between the temperature difference and airflow in the box for free convection ventilation (Figure 16). According to this a temperature difference of 0.26° C represents an airflow rate through the potato pile of 13.2 $m^3/t{\bullet}h$ (Figure 16). The maximum temperature difference during the long-term storage was 2° C.

At a potato pile height of 1 m and a temperature difference of 1° C our measurements showed an airflow rate of 34.6 m^3/t•h. In the case of a 68% prediction interval the airflow rate amounts between 24.0 up to 45.2 m^3/t•h. An airflow rate of 34.6 m^3/t•h is slightly above the value of 26 m^3/t•h calculated by Maltry (1997).

The studies have shown that with the aid of a measuring hopper it is possible to measure the airflow rate through the boxes. Even if the values measured for airflow through potatoes in boxes coincide well with theoretically calculated values, it must be noted that for reasons of measuring technology the air velocity was always only measured at one box. Further investigations are planned for the next storage period.

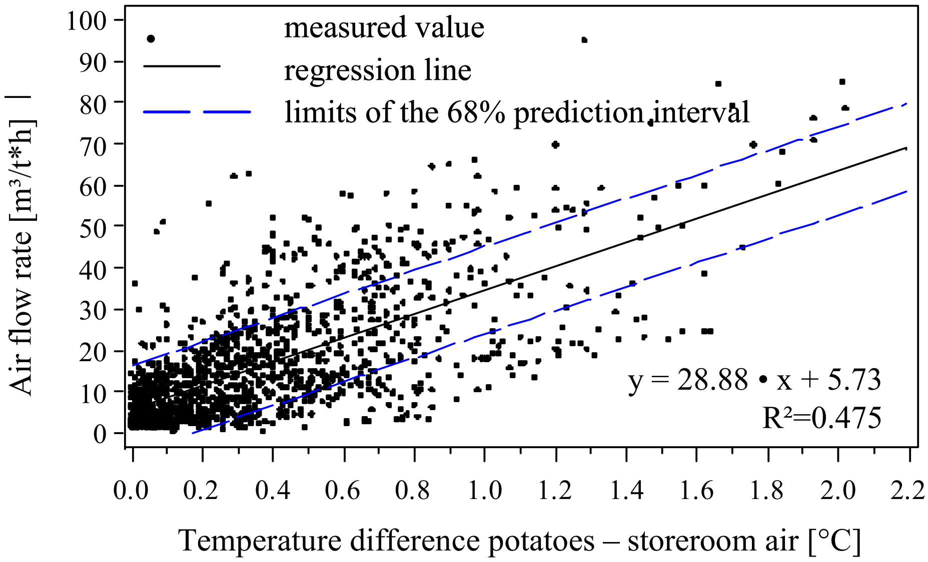


Figure 16. Measured air flow rate at 1 m potato pile as a function of the temperature difference potatoes-storeroom air, direct box filling

Only slight differences of the tuber temperature result from the comparison between direct and indirect box filling. By comparison with tubers filled indirectly, tubers filled directly react more quickly to changes in air temperature. During the main storage phase the boxes that had been filled directly were on average only 0.3° C cooler than boxes filled indirectly. The reasons for this unexpectedly low difference are probably the low content of foreign material of 4.12°% by weight (Table 2) and a relatively uniform distribution of foreign material with both filling variants. That allowed good ventilation for both filling variants.

As regards losses of weight during the 6 month storage period it was shown that directly filled tubers of the variety Princess 2004 sustained lower loss levels than tubers filled indirectly (Figure 17). In the preceding investigation years too the tubers filled directly had sustained less loss of weight, even if the difference by comparison with indirect filling was not always significant. The boxes with better ventilation showed lower mass losses. Furthermore, our own studies showed that the tubers filled directly are treated very gently and showed a lower transpiration intensity and hence lower metabolic action after the harvest (Maly et al. 2005). Thus a further reason for the low weight losses lie in the low mechanical stress of the tubers when the boxes are filled.

Distinctly higher weight losses were ascertained for bulk storage. The tubers in bulk storage are handled several times and subjected to mechanical stress. A further reason for the high weight losses is to be seen in intensive forced ventilation in bulk storage.

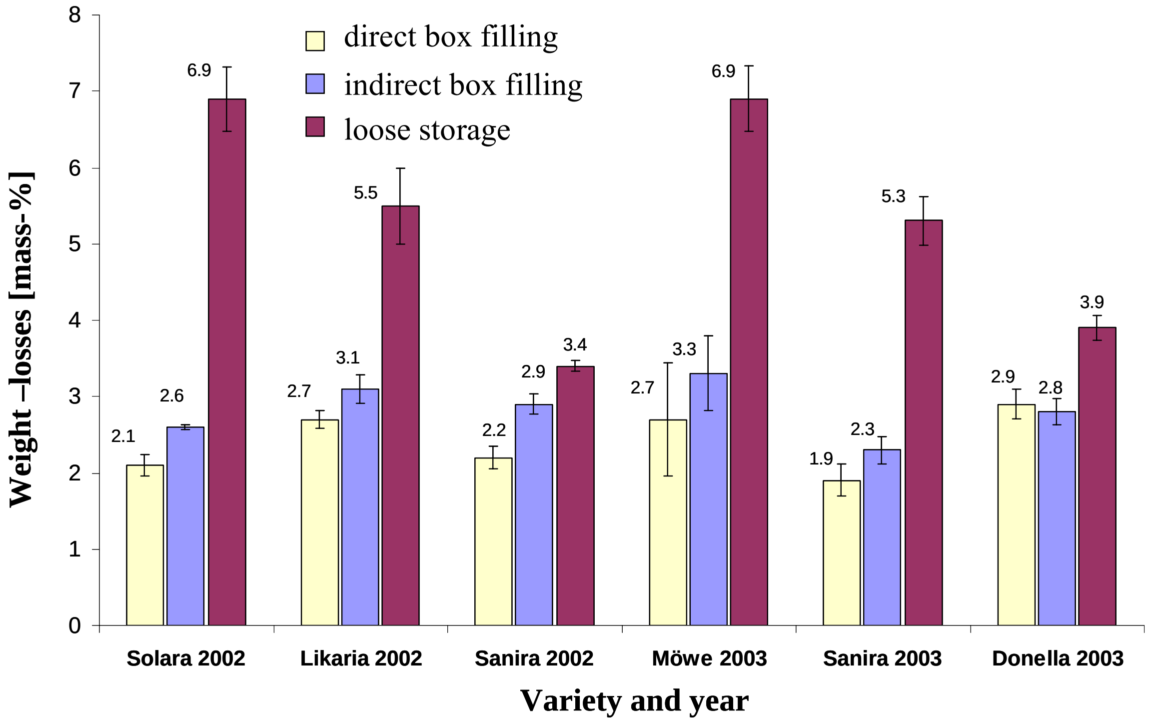


Figure 17. Weight losses of potatoes after 6 months of storage, mean value and standard deviation of 6 measurements

5. CONCLUSION

If foreign material cannot be avoided when potatoes are taken into storage, then at least uniform distribution of the foreign material is to be targeted. By filling the boxes on the harvesting machine, foreign material is distributed uniformly and as a result the boxes are filled in a manner favourable for ventilation.

In agreement with the measurements of the flow profile, the pictures taken with the infrared thermography camera show that if foreign material is distributed unevenly the middle of the box is hardly ventilated at all.

As the measurements on the storage box with the measuring hopper have shown, the air velocity in free convection ventilation rarely reaches values above 0.01 m/s.

During the long-term storage the tubers were on average 0.26° C cooler than the air in the storage hall. This low temperature difference leads to an airflow rate of about 35 m^3/t•h and is sufficient for storing the tubers.

The tuber temperature that is on average about 0.3° C lower in the case of direct box filling than in indirect filling does not lead to any difference in the quality of the potatoes. A higher foreign material component would presumably cause greater temperature differences.

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